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(54) **Buoyant antenna**

(57) A buoyant antenna comprises a slot (10) formed in a cylindrical conductor, for example by the edge opening in a single turn roll-resonator of metal clad plastic dielectric sheet material (11), the slot being substantially one free-space wavelength long at the operating frequency and short circuited at each end (12). Varactor diodes (13) are connected across the slot. Low frequency modulation of the varactor diode bias effects tuning of the antenna. The roll-resonator may be encased in a jacket of foam dielectric (20). A pilot signal can be injected, via the varactor feed lines. As shown there is an overlap *s*. In an alternative arrangement an insulating cylinder carries a conductive layer with a gap in it, and the provision of a conductor without an insulating cylinder is envisaged.

Fig.1.

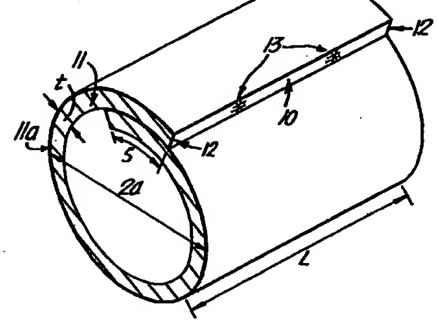


Fig.1.

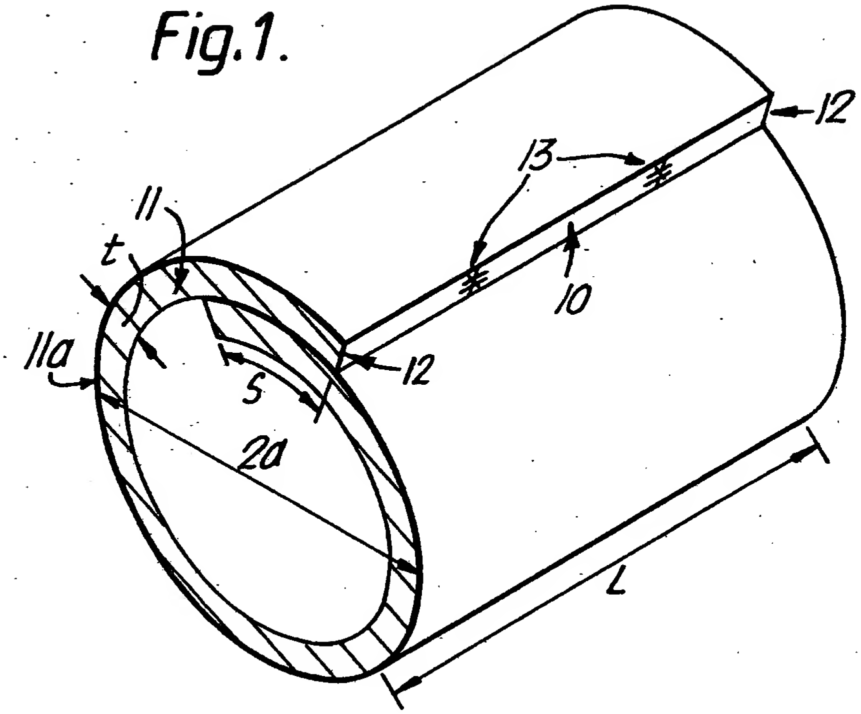


Fig.2.

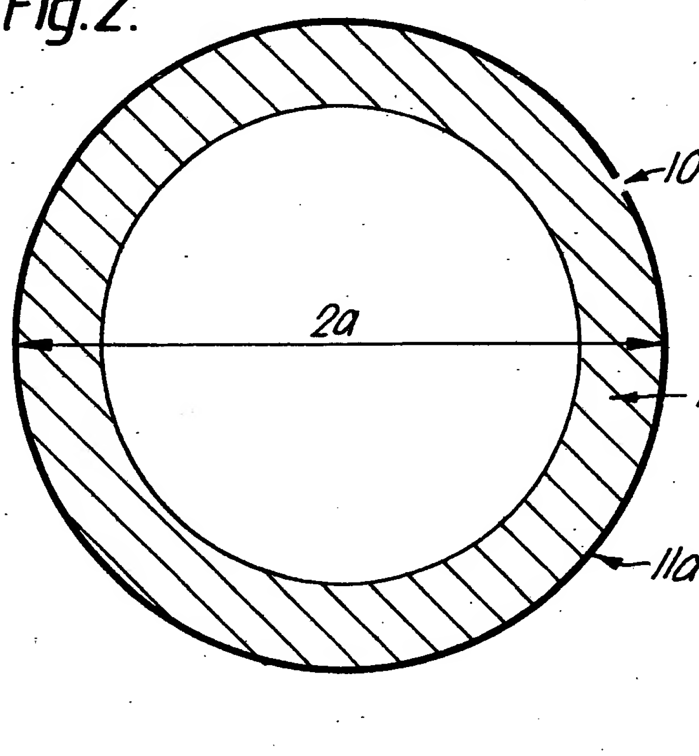


Fig.3.

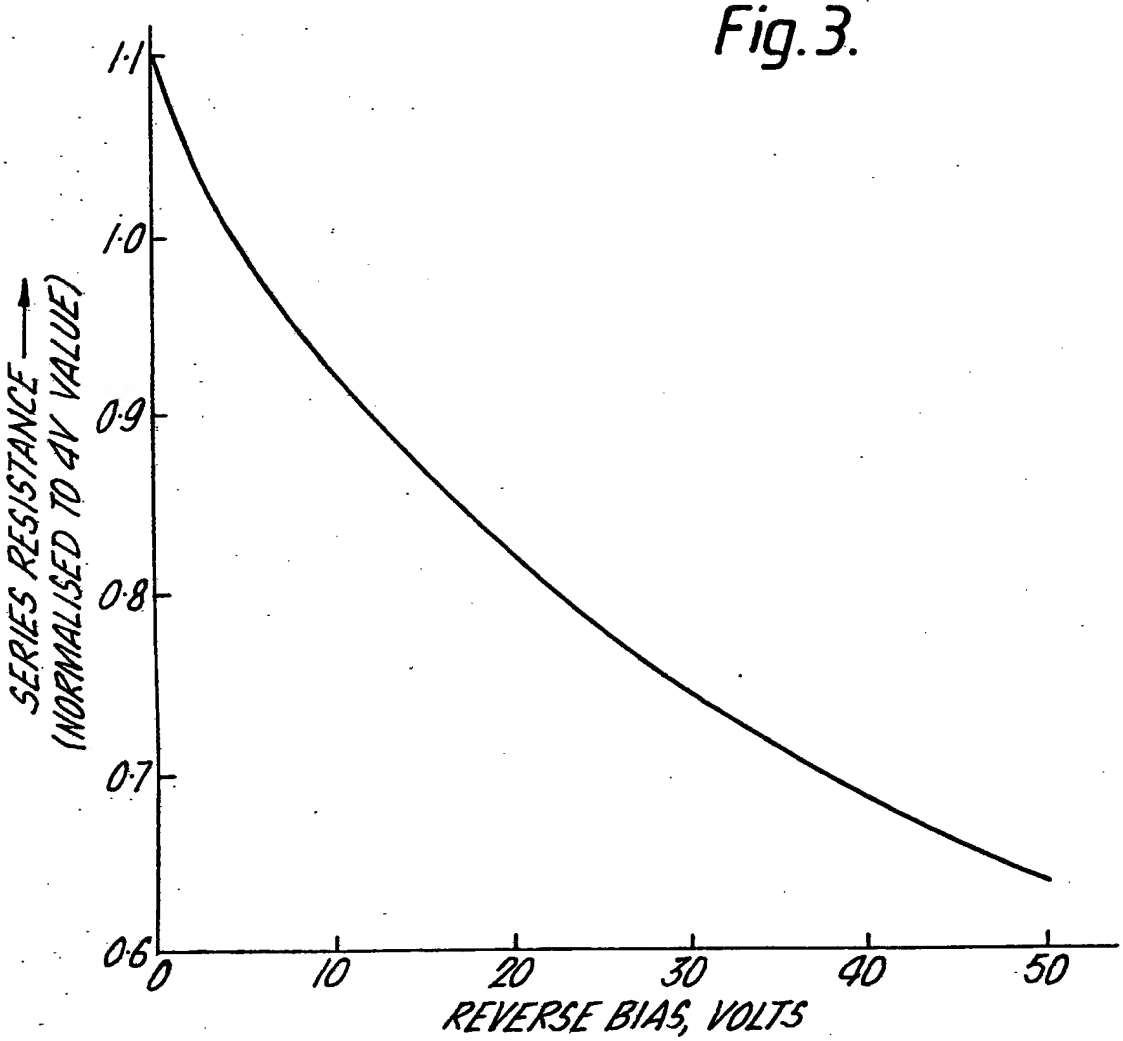


Fig.4.

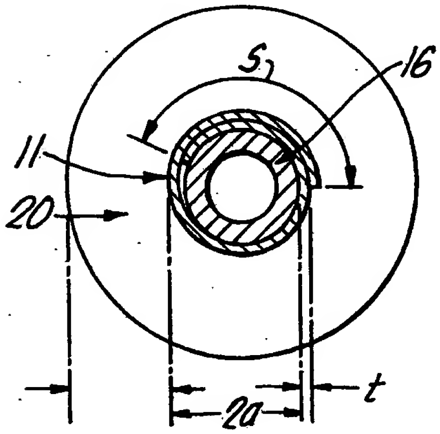
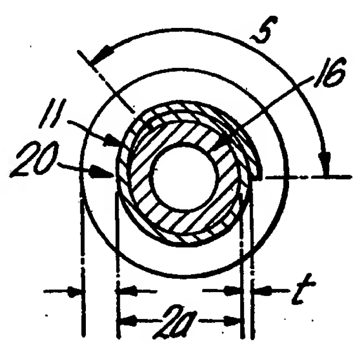


Fig.5.



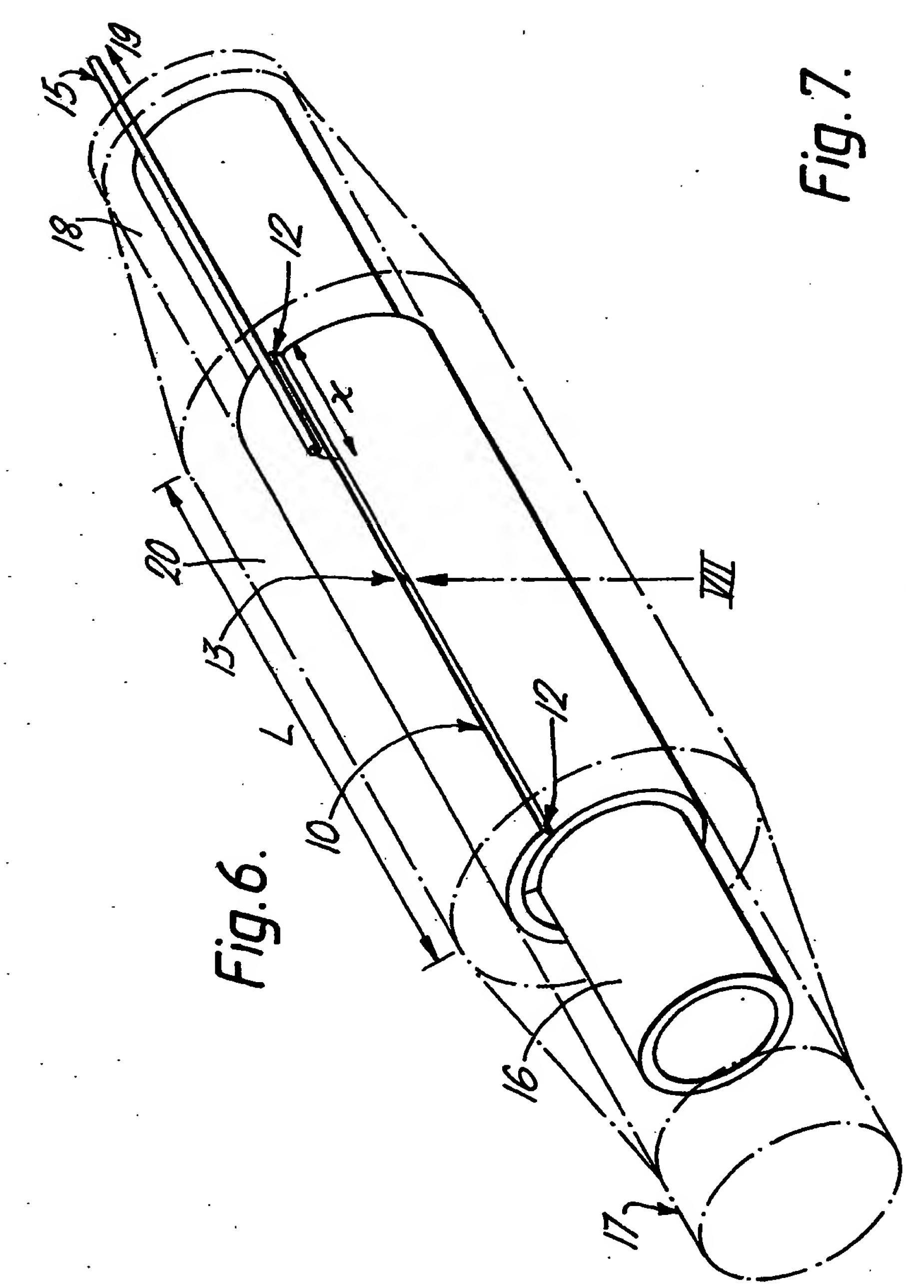


Fig.6.

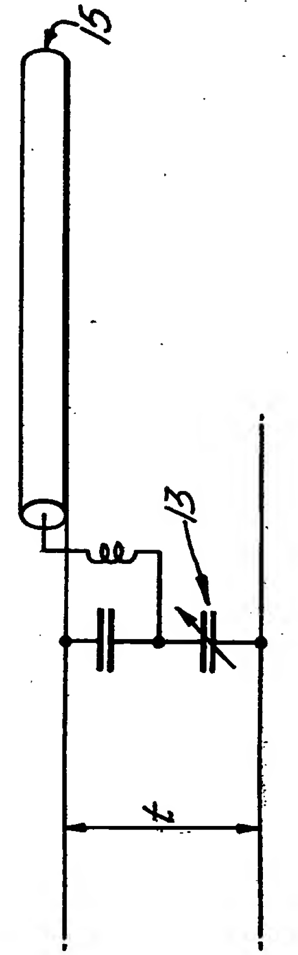


Fig.7.

SPECIFICATION

Buoyant antenna

This invention relates to a buoyant antenna which can be towed at a distance behind a marine craft for radio communication purposes.

A buoyant antenna is disclosed in the paper "A Slender Resonator—Slot Antenna" by J. C. Lee, IEE International Conference on Antennas and Propagation, Conf. Publ. No. 195, pp 442-446, 1981. Essentially the antenna disclosed comprises a slot formed by the edge opening in a roll-resonator of copper clad plastic dielectric, approximately 1/2 free-spaces wavelength long. The slot is short circuited at the two ends, and the antenna is fed by a coaxial line the inner and outer conductors of which are soldered to respective sides of the slot.

According to the present invention there is provided a buoyant antenna comprising a slot formed by the edge opening in a single turn roll-resonator of metal clad plastic dielectric material, the slot being substantially one free-space wavelength in length at the operating frequency and short circuited at each end, the antenna including at least one varactor diode connected across the slot whereby the antenna is tuned.

In a preferred embodiment of the antenna the roll-resonator is totally enclosed in a foam dielectric jacket.

Embodiments of the invention will now be described with reference to the accompanying drawings, wherein

Fig. 1 illustrates a basic roll-resonator with a radiating slot,

Fig. 2 illustrates an alternative resonator to that of Fig. 1 but without any overlay,

Fig. 3 illustrates a varactor diode series resistance characteristics,

Fig. 4 illustrates the design of a non-tunable buoyant antenna,

Fig. 5 illustrates the design of a tunable buoyant antenna,

Fig. 6 illustrates the construction of a tunable buoyant antenna, and

Fig. 7 illustrates details of the varactor feed circuit.

The buoyant antenna consists essentially of a slot 10 formed by the edge opening in a roll-resonator of copper clad polythene 11 of just over one turn, as indicated in Fig. 1, where a is the resonator radius, L its length, s the amount of overlay and t the dielectric thickness. The slot 10 is shorted at each end 12, so that a sinusoidal voltage variation is maintained along the slot length. The resonator dimensions determine the resonant frequency, and the resultant antenna has a narrow bandwidth of around 1% and a relatively high input resistance. Tuning is obtained (on receive) by the use of one or more varactor diodes 13. Dimensional trade-offs help to attain the greatest tuning bandwidth with available varactor diodes whilst maintaining other desirable features such as low losses and reasonable cross-section dimensions.

The actual control of the varactors involves a small modulation signal on the varactor bias. This modulation is recovered from the received signal in a phase-sensitive detector (not shown) and used to control the bias so as to "hill-climb" to maximum received signal. This method may fail in the absence of an incoming signal, or when the latter is too weak. To prevent the varactor from useless hunting, a minute pilot signal of the requisite frequency can be injected at the antenna to provide a weak but reliable signal for the varactor control circuits. Tuning is accomplished, inter alia, by altering the frequency of the pilot signal. The varactors then automatically track and the antenna remains on tune. Although the pilot signal will radiate, this radiation is no different from the re-radiation that the antenna will do in any case, when it acts as a receiver. The varactor sensitivity is about 5 MHz/V so a varactor modulating signal of some tens of mV is needed. The pilot signal would be around a microvolt, with a radiation of a few thousands of a picowatt, very substantially less than a typical oscillator leakage signal. The pilot signal can be conveniently injected via the varactor feed lines.

The choice of the resonator length L to equal half the free-space wavelength, as indicated by Lee, is not mandatory, and a greater length, such as a full wavelength, would have advantages in lowering the slot input impedance from about 1000Ω to 305Ω. This would help the matching to the feed line and would also assist in reducing the impact of extraneous losses.

To obtain a large tuning range clearly requires a large change in varactor capacitance with tuning voltage. For the Alpha Microwave Semiconductors DVH-6700 range of varactors a capacitance ratio of 4.5 is obtainable with the 30 volt series, rising to 8.2 with the 90 volt series. However, the latter do not reach the same maximum values, and have a much lower Q-factor, so practical considerations may lead to working with the lower capacitance-ratio devices. In any case, the extreme limit would be reached if *all* the capacitance were varactor provided, reducing the overlay capacitance to zero. This can probably not be done while maintaining the overlay-type geometry, since the radiating slot is the open edge of the overlay capacitor. A minimum overlay arc several times the dielectric thickness would be needed to create the slot and isolate it from end effects at the far end of the overlay capacitor. Alternatively, the geometry could be modified, as indicated in Fig. 2, in which the dielectric takes the form of a cylindrical tube of radius a, and the copper cladding is an almost compete arc with a small gap constituting the radiator.

The tuning capacitance is provided by a number of varactors distributed along the slot length. Something like λ/10 spacing is the largest compatible with giving the effect of uniform loading, but other considerations may call for a smaller spacing.

The tuning frequency f can be related to capacitance in equation

The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

$$f = \frac{3.10^8}{2L}\left[\frac{1}{\varepsilon_r} + \frac{L^3}{36\pi^4 a^2\, C_{nF}}\right]^{1/2} \qquad (1)$$

Where ε_r is the relative permittivity of the metal clad dielectric.
For $L = 1.2$ m and $\varepsilon_r = 2{,}25$ this becomes

$$f_{MHz} = 83.3\left[1 + \frac{11.1}{a^2_{cm}\; C_{nF}}\right]^{1/2} \qquad (2)$$

Depending on the varactors used, the overlay capacitance, if any, and allowance for any other "dead" capacitance, this formula can be used to evaluate the tuning range.

We take, as an example, the case $\alpha = 2$ cm, C_{nF} given by 9 type 22 varactors, which provide a maximum of 378 pF at zero volts. Hence the lower tuning limit, from (2) is

$f_{min} = 242$ MHz (3)

From the data sheets, the minimum capacitance is $378/4.5 = 84$ pF, achieved at 30 volts reverse bias. Hence, from (2)

$F_{max} = 490$ MHz (4)

giving a better than 2 to 1 tuning range. However, this is an extreme situation, and jacket capacitance is likely to reduce the upper limit to between 350 and 400 MHz.

Reference is made here to the data sheets of Alpha Microwave Semiconductors as typical of what is available commercially for high-Q varactors. There are two basic types: DVH-6700 which is a packaged device; and CVH-2000 which is the identical varactor in chip form. Probably the latter would be more suitable for the antenna application, but because of the way the data is presented, reference is here made to the packaged device.

The Q is specified at 4 V reverse bias, at a frequency of 50 MHz. No data is given on the Q at other bias values, though it is known that the series resistance decreases with bias as the capacitance drops. Since the extreme value occurs at 0 volts, where the capacitance is greatest, the increase of series resistance from 4 V to zero bias is a needed figure. Our research indicates a rise in resistance of some 10% between 4 and zero volts, and in the absence of more specific information the data-sheet values of Q will be decreased by 10% to refer to the zero volt condition. The factor involved is not large, and probably no serious error is introduced thereby.

As far as the frequency is concerned, the Q varies inversely, so a factor 5 is involved when referring to a design frequency of 250 MHz.

The varactor loss resistance loading the slot is

$R_{var.} = Q/\omega C_{var.}$ (5)

but this is the value for a single varactor at its terminals. When used in numbers to stimulate continuous loading the sinsusoidal slot voltage distribution reduces the effectiveness of the varactor capacitance, but in the same way as that of the resonator inductance and overlay capacitance, so that their *ratio* is unaffected. The same would be true for the loading resistance and the slot resistance if the latter were referred to the mean squared voltage. However, the slot resistance is actually quoted as referred to the voltage maximum, and its value is therefore effectively doubled. To allow for this when comparisons are made, either the value used for the slot resistance should be halved or the vcaractor loading figure should be doubled. Since the quoted slot resistance is the actual resistance seen by a feed at the slot centre it would probably be misleading to tamper with it. Thus (5) will be doubled to take account of the continuous loading simulation, and the net loading resistance becomes.

$R_{var.} = 2Q/\omega C_T$ (6)

where C_T is now the *total* varactor capacitance used, i.e. the single varactor capacitance times the number of varactors used.

If $Q_{50,4}$ is the 50 MHz, 4 volt value taken from the data sheet then (6) can be written

$R_{var.} = 100\, Q_{50,4}/(g\, f_{MHz}\, \omega C_T)$ (7)

where g is a factor about which little is known other than that, by definition, it equals unity at 4 V bias, and, in the instance for which data is available, its variation with bias voltage is as shown in Fig. 4. (This particular device is approximately equivalent to a DVH-6700 type 23 with a 60 V bias range.) Since C_T, in the present application, drops faster than the inverse square of the resonant frequency it tunes, whilst g also drops substantially with increase in bias voltage, the expression in (7) has its smallest value at the lowest frequency, i.e. at zero bias volts where g is taken as 1.1.

Equation (7) can be re-written

$$R_{var.min.} = \frac{231\, Q_{50,4}}{C_{T,0;\,pF}}\left(\frac{250}{f_{MHz}}\right)^2 \qquad (8)$$

where $C_{T,0;pF}$ is the total varactor capacitance at 0 volts bias, in picofards; $R_{var.min.}$ is the smallest net varactor loading resistance encountered; and f_{MHz} is the lowest tuning frequency encountered at zero bias. (The reason the Q-factor at 4 V bias appears here is because this is the value quoted in the Alpha data sheets. Should $Q_{50,0}$ (the Q at zero bias) be quoted in some other source then $Q_{50,4}$ in (8) should be replaced by $1.1Q_{50,0}$).

It is the value obtained from (8) which has to be compared with the slot resistance R_s. If the slot length is 1.2 m then, near 250 MHz.

$R_s \approx 305\,(250/f_{MHz})^2\,\Omega$ (9)

Thus, in comparing (9) with (8) the factor $1/f^2_{MHz}$ appears in both, so that the decrease of the effect of the loading at increasing frequency comes from the decrease of g and C_T with increased bias.

The jacket is needed to handle the situation in which the slot rotates under the water. Lee was concerned with the mis-tuning produced by this, and gave curves for jacket thickness T to keep the mis-tuning within 1%. This is not a consideration if instantaneous varactor tuning is used; rather, it is the 'dead' capacitance when the maximum jacket capacitance is superposed on the slot that limits the tuning range. It can always be controlled by using a large jacket diameter, but size limitations may not permit this. The maximum jacket capacitance may be given as

$C_{J,max.} = \varepsilon_0 La\pi/2T$ (10)

For $a = 2$ cm, $L = 1.2$ m and $T = 4.5$ mm, this gives a value of 74 pF. If L and a are specified, only an increase of the jacket thickness is available to reduce this, with a resulting enlargement of the overall diameter.

The limiting factor in a practical design is likely to be the total outer diameter, twice the sum of the resonator radius and jacket thickness. Making the jacket thinner increases the standing capacitance, which reduces the tuning range. Reducing the resonator radius increases the needed tuning capacitance. If this is provided entirely by varactors, (8) indicates a lowering of the loss resistance, leading to a less efficient antenna. Alternatively, if some overlay capacity is used, the tuning range is substantially reduced, though the additional effect of the jacket capacitance is then reduced as well. This permits the use of a somewhat thinner jacket, and this is further helped by the effect of the resonator radius reduction, as indicated in (10).

The parameters of interest are thus the tuning range, the antenna efficiency, and the overall diameter. A secondary consideration is the number of varactors needed, and the cost per varactor type utilized. In all designs the length is taken as 1.2 m, and they are thus based on equation (2) for the tuning range, and (8) and (9) for the losses. The antenna efficiency is given by

$$\eta = R_{var}/(R_s + R_{var.}) \qquad (11)$$

on the assumption that other sources of loss are negligible. Equation (11) need only be evaluated at the lowest frequency, since the efficiency rises rapidly as the frequency increases. A band from approximately 220 to 440 MHz is of potential interest, with particular attention to 250 MHz. It may be noted that the jacket only affects the higher frequencies, since, at the lower end of the band the varactor control simply lowers the varactor capacitance to match the jacket contribution. It can, of course, no longer do this when minimum capacitance is reached, which is why the jacket sets an upper limit to the tuning range.

Since standing capacitance reduces the tuning range, the use of overlay capacitance is to be avoided where possible. For a large resonator radius the needed tuning capacitance can all be provided by the varactors without undue influence on the antenna efficiency. As the radius is reduced the needed tuning capacitance rises as the inverse square of the resonator radius, and a point is reached where the varactor resistance loading becomes quite deleterious. There then enters the possibility of a trade-off between loss and tuning range.

The total capacitance needed for tuning is given by

$$C = \frac{\lambda_o^{\,3}}{128\pi^4 a^2} \ \mathrm{nF} \qquad (12)$$

With $L = \lambda_o$ this is the capacitance that *must*, in total, be provided to bring the resonator on tune. If tuning varactors are used, then part of (12) is met by a reduced overlay, and part by the varactors.

Equation (12) gives the *total* capacitance needed for tuning; at 250 MHz, with $L = 1.2$ m,

$$C = 1.38/a_{cm}^2 \ \mathrm{nF} \qquad (13)$$

Equation (2) gives the resonant frequency at any resonator radius and capacity; for $L = 1.2$ m, $\varepsilon_r = 2.25$,

$$f_{MHz} = 83.3\left[1 + \frac{11.1}{a^2_{cm}\, C_{nF}}\right]^{1/2} \mathrm{MHz} \qquad (14)$$

Equation (5) gives the maximum jacket capacitance; for $L = 1.2$ m,

$$C_J = a_{CM}/6T_{mm} \ \mathrm{nF} \qquad (15)$$

Equation (8) gives the varactor loading resistance. It is lowest at zero varactor bias, and F_{MHz} in the equation should be taken from (14) in which C_{nF} is the total capacitance used, and comprises overlay capacitance (if any) and total varactor capacitance at zero bias,

$$R_{var.min} = \frac{0.231\, Q_{50,4}}{C_{T,0;nF}} \left(\frac{250}{f_{MHz}}\right)^2 \ \Omega \qquad (16)$$

Equation (9) gives the slot radiation resistance for $L = 1.2$ m,

$$R_s = 305\,(250/f_{MHz})^2\,\Omega \qquad (17)$$

Here, f_{MHz} is any frequency of interest, and is given by (14) at the bottom of the band. This value should be used when comparing (16) and (17).

Equation (11) gives the antenna efficiency, and is found by combining (16) and (17)

$$\eta = R_{var.}/(R_s + R_{var.}) \qquad (18)$$

or

$$-10 \log_{10}(1 + R_{sd}/R_{var.}) \ \mathrm{dB} \qquad (19)$$

Some examples are given.

Design 1, Outer Diameter 2 Inches

The resonator radius is taken as 2 cm and the jacket thickness as 5.4 mm, to give an overall diameter of 2 inches. The choice of varactor type and number is not critical. We take 11 of type 22 for which C_o is 42 pF and $C_{30} = 42/4.4 = 9.55$ pF. The Q_{50} at 4 V bias is quoted as 1800.

From (14) the lowest tunable frequency is

$f_1 = 220$ MHz

From (15) the maximum jacket capacitance is 61.5 pF. Hence the total minimum capacitance is $11 \times 42/4.4 + 61.5 = 166.5$ pF, and (14) gives the highest available tuning frequency as

$f_2 = 350$ MHz.

(In the absence of jacket capacitance this would have been 436 MHz.) From (16), $R_{var.}$ at 220 MHz is 1160 Ω, whilst from (17), $R_s = 394$. Hence, from (18) and (19),

$\eta = 0.75$ or -1.27 dB

The tuning band is ± 23 per cent, centred on 285 MHz.

Design 2, Outer Diameter 1.5 Inches

The resonator radius is taken as 1.5 cm and the jacket thickness as 4.05 mm, to give an overall diameter of 1.5 inches.

We take 12 of type 25 for which $C_o = 63$ pF, $C_{30} = 63/4.5 = 14$ pF. The Q_{50} at 4 V bias is given as 1400.

From the equations it is found that $C_J = 61.5$ pF and

$f_1 = 228$ MHz

$f_2 = 394$ MHz

$\eta = 0.60$ or -2.32 dB

The tuning band is ± 27 per cent centred on 311 MHz.

Design 3, Outer Diameter 1 Inch, No Overlay Capacitance

The resonator radius is taken as 1 cm and the jacket thickness as 2.7 mm, to give an overall diameter of 1 inch. The needed capacitance is rather large. We take

18 of type 27 for which $C_o = 90$ pF, $C_{30} = 90/4.5 = 20$ pF and $Q_{50,4} = 1200$. Then $C_J = 61.8$ pF and the equations give

$f_1 = 233$ MHz
$f_2 = 435$ MHz
$\eta = 0.36$ or -4.44 dB

The tuning band is ±30 per cent centred on 334 MHz.

Design 4, Outer Diameter 1 Inch, Overlay Capacitance Included

The same resonator and jacket size as used in design 3 are taken, but some overlay capacitance is included in order to reduce the varactor loading and hence the antenna loss. An overlay of 550 pF is taken by way of example. If s is the overlay arc, the capacitance, neglecting fringing, is $\varepsilon_r Ls/36\pi t$ nF, where t is the dielectric thickness. For example, with t = 0.254 mm = 1/100 inch, the formula requires s = 0.585 cm to give 550 pF. This is "dead" capacitance, and has to be added to the jacket capacitance in calculating the upper resonant frequency, where its effect is substantial. We take 17 of type 25 for which $C_o = 63$ pF, $C_{30} = 63/4.5 = 14$ pF, and $Q_{50,4} = 1400$. The equations give

$f_1 = 233$ MHz (unaltered)
$f_2 = 313$ MHz
$\eta = 0.5$ or -3 dB

The tuning band is ±15 per cent centred on 273 MHz.

The cost of picking up 1.44 dB in antenna efficiency is a substantial loss of 122 MHz in tuning range.

In a general way we see an increase in tuning band, centre frequency and losses as the resonator radius is reduced, for the case of a constant jacket capacitance and no overlay. The overlay is quite damaging for the tuning range, with not too much saving on antenna efficiency. Incidentally, the great value of increasing the slot size to 1.2 m, with the consequent reduction of the radiation resistance to around 300 Ω from about 1000 Ω is readily seen.

These four examples of design do not in any way claim to be optimum, and the trade-off in antenna loss and use of considerable number of varactors is something that has to be assessed separately before optimum resonator radius and jacket thickness can be determined.

The use of other varactor types, such as, for example, type 22 with 60 V range, in Design 1, would extend the tuning range, because of the 7:1 capacitance reduction compared to the 4.5:1 reduction for the 30 V type, to 395 MHz from 350 MHz. The cost is a drop in $Q_{50,4}$ from 1800 to 1000, with a consequent reduction in antenna efficiency from 0.75 to 0.62, increasing the loss from 1.27 dB to 2.07 dB. Whether the extra 45 MHz tuning is worth the increse of 0.8 dB in loss will depend on system considerations.

In Equation (1) for the resonant frequency the quantity ε_r appears because, in the derivation, the radiating slot is in the form of an edge opening in an overlay capacitor made from material with permittivity ε_r. So long as the structure uses an overlay arc at least a few times the dielectric thickness, say a 1 mm arc for a dielectric thickness t of 0.254 mm, then the field is concentrated in this material, small though it may be in total volume, and the radiation out from the slot is detemined by waveguide characteristics in which ε_r plays its part, at least in the absence of loading capacitance.

However, in the geometry of Fig. 2 the overlay has been dispensed with. The dielectric is shown in the form of a complete cylindrical tube of unspecified thickness, whose main purpose now appears to be mechanical support for the metal cladding. In fact the latter could probably be a somewhat thicker self-supporting metal cylinder with a longitudinal gap short-circuited at the ends. What role does the dielectric now play? At one extreme it could completely fill the metallic cylinder. At the other it could be completely removed. Since the metallic cylinder is supposed to be acting as an elongated single turn inductance, the material filling its interior should be of no consequence as long as its permeability is that of free-space. The only place where the dielectric seems to be able to exert any influence is in the neighbourhood of the slot, where the electric field lines penetrate into the cylinder by an amount several times the slot width. For example, if the slot is 1/100 inch wide (as it would be in the overlay case), then if the dielectric tube were, say, 5 times thicker than this, virtually all the eletric field lines inside the tube would be within the dielectric. Putting in more dielectric would hardly alter things. Under these circumstances, should ε_r appear in (1), or should it be replaced by unity? The loading capacitance certainly reduces the relative capacitance effect of any electric field lines in the dielectric, if this shows up in the terms in $(f_{co}/f)^2$. Is a further reduction called for? Since f_{co} is really the cut-off frequency calculated from $\omega^2LC = 1$ the question is to find the *additional* role of the dielectric in determining the actual cut-off in the slotted structure. This does not appear to be a simple problem, and all that can be said at the moment is that (2) should be replaced by

$$f_{MHz} = 83.3 \left[K + \varepsilon_r(1-K) + \frac{11.1}{a^2_{cm} C_{nF}} \right]^{1/2} \quad (20)$$

where K = 1 in the absence of varactor loading and (probably) K approaches zero as the varactors take over. This alters the tuning range somewhat. Thus, in Design 1, with K = 0 rather than 1, the lower frequency limit would be increased to 239 MHz. If the number of varactors were increased to 14 to maintain the lower limit, the upper limit would suffer accordingly, though it would be slightly less susceptible to the influence of the jacket. The loading resistance would also be reduced, with an addition 0.3 dB loss in antenna efficiency.

This matter is not one of major concern but it will need to be resolved eventually in order to permit more precise design formulas to be used for the tuning range.

One further possibility should be considered, and that is to construct the radiating slot in the form of a single turn helix. The advantages that seems to accrue from this are that the jacket capacitance seen by the slot, although varying somewhat from end to end, would appear constant in total, and at two thirds of its maximum value. This would ease the mistuning as the slot rotates, in the case of the untunable antenna; and would reduce, by a third, the standing capacitance in the case of the tunable antenna.

Fig. 4 shows a cross-section through a non-tunable antenna in which the core is a phenolic tube of 2 cm outside diameter around which is wrapped a polythene sheet 0.01 inches thick clad on one face with a copper foil about 0.001 inches thick. The amount of overlay is 2.365 cm and the whole is encased in a dielectric foam jacket of 1.4 cm thickness, the dielectric foam having essentially unity relative permittivity. The buoyancy of the completed structure should be such that the jacket at least breaks the water surface. Fig. 5 illustrates a cross-section through a corresponding tunable buoyant antenna. Note that whereas the phenolic tube core is still 2 cm outside diameter and the copper clad polythene sheet is the same thickness, the inclusion of the tuning varactor diodes results in a reduction of the overlay to 1.95 cm and a reduction in the jacket thickness to 4.5 mm. As shown in Fig. 6 the radiating slot 10 is 60 cm in length and has short circuits 12 at each end. The varactor diode(s) 13 is connected across the slot. The feed is via coaxial cable 15 the inner conductor of which is soldered to one side of the slot and the outer conductor to the other side of the slot. The phenolic tube 16 is extended beyond the ends of the resonator and the tube ends are encased within metallic cylinder continuations 17, 18 of the resonator. The ends 17, 18 of the metallic cylinder are closed, and one end is attached to a towing cable 19. The dielectric foam jacket 20 extends beyond the resonator ends and is tapered beyond the resonator ends to provide a smooth profile for towing in the sea. Fig. 7 shows the details of the varactor feed circuit.

One optional feature is the inclusion in the antenna feed of some form of pre-amplifier, e.g. a MOSFET device at the centre of the slot, designed to match directly into the impedance of the slot.

CLAIMS

1. A buoyant antenna comprising a slot formed by the edge opening in a single turn roll-resonator of metal, the slot being substantially one free-space wavelength in length at the operating frequency and short circuited at each end, the antenna including at least one varactor diode connected across the slot whereby the antenna is tuned.

2. A buoyant antenna according to claim 1, wherein the resonator roll exceeds the single turn by an amount to form an overlay of one end of the roll by the other end of the roll, the slot width being defined by the dimension of the dielectric gap between the roll and the overlay.

3. A buoyant antenna according to claim 1 or 2 wherein the roll resonator is fabricated from a metal clad plastics dielectric material.

4. A buoyant antenna according to claim 1, 2 or 3 including a high impedance pre-amplifier feed device matched to the slot impedance, the pre-amplifier device feeding the slot near the centre.

5. A buoyant antenna according to any preceding claim including means for feeding the varactor diod(s) with a low power bias modulation signal, means for extracting said modulation signal from a signal received at the antenna and utilising the extracted signal to control the bias.

6. A buoyant antenna according to any preceding claim having a plurality of varactor diodes connected across the slot at substantially equal intervals along its length.

7. A buoyant antenna according to any preceding claim, including means for feeding the varactor diode(s) with a pilot signal and means for controlling the pilot signal frequency to effect tuning of the antenna.

8. A buoyant antenna according to any preceding claim, including an external jacket of foam dielectric material which completely encompasses the antenna.

9. A buoyant antenna according to any preceding claim, wherein the slot is formed as a single turn helix.

10. A buoyant antenna substantially as described with reference to the accompanying drawings.

11. A method of tuning an antenna formed by a slot in a substantially single turn roll-resonator including the steps of incorporating varactor diode(s) across the slot and applying a low frequency bias modulation to the diode(s).

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